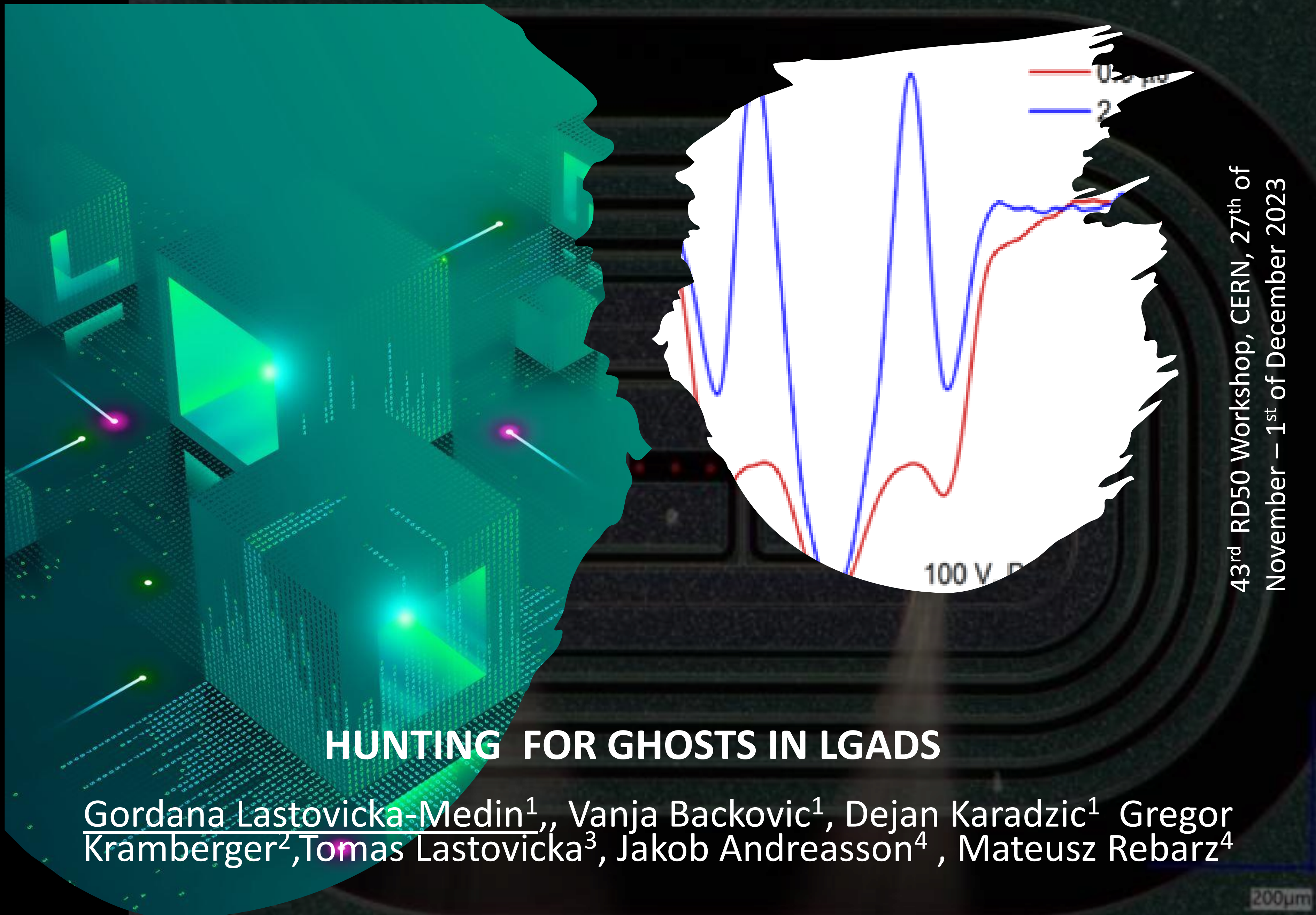

HUNTING FOR GHOSTS IN LGADS

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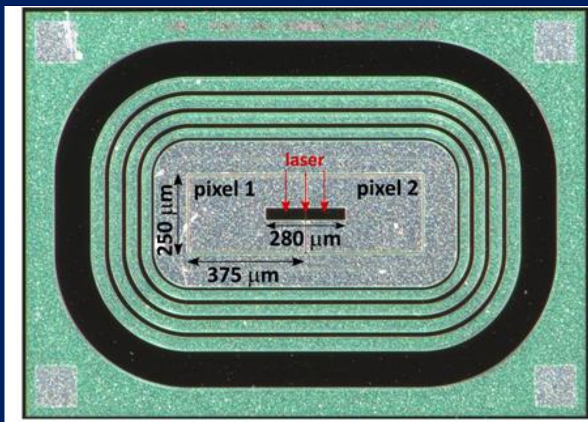
43rd RD50 Workshop, CERN, 27th of November – 1st of December 2023

OUTLINE

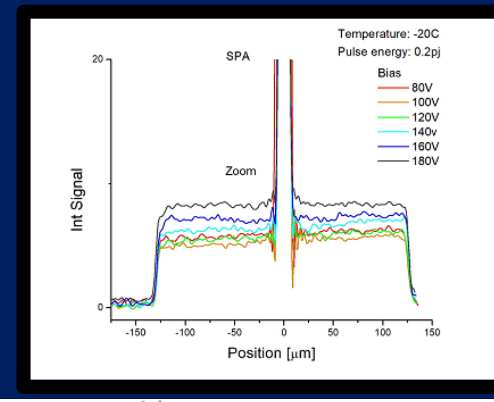
- Introduction (Motivation)
- Experimental technique
- Investigating ghosts in Double Trenched Ti-LGADs
- Conclusion

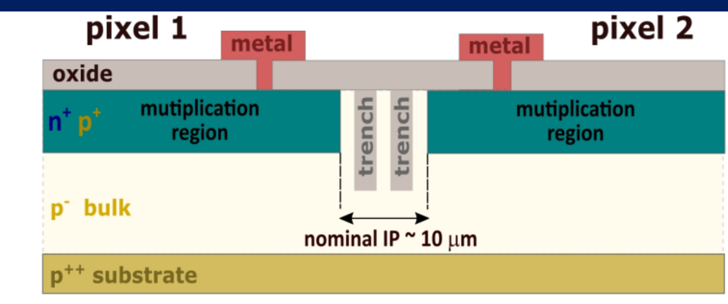
Introduction

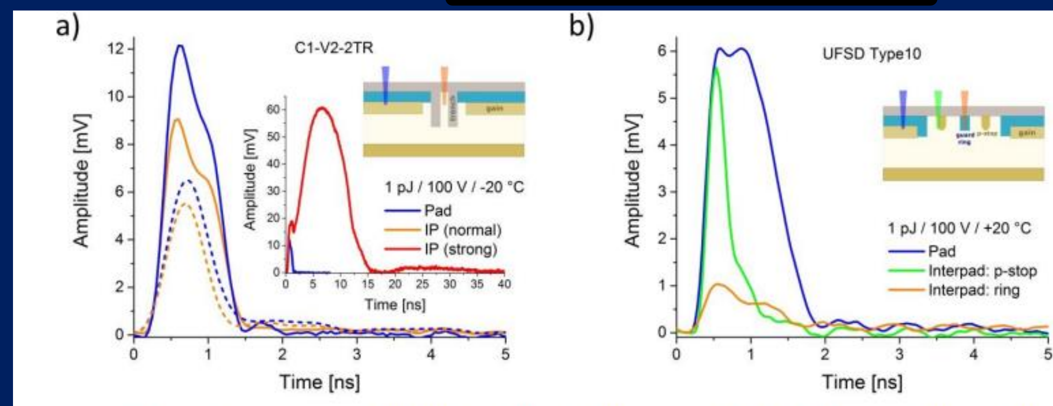
The signal in the IP of Doble Ti-LGAD region exhibited a dual character. Aside from the “normal” fast signal, the waveforms with significantly higher amplitude and width (~ 10 ns) were observed. This signal is labelled as “strong” .



W11: C1-V2-2TR







TCT waveforms generated by 1 pJ laser pulses at 100 V in pad and interpad areas of LGADs: a) pad and “normal” IP signal in 2TR LGAD for non-irradiated sensor (solid line) and irradiated (8×10^{14} n_{eq}/cm^2) sensor (dashed line); Inset: comparison with “strong” IP signal for the same sensor; b) an example of pad and two IP (p-stop and bias ring) signals for Type10 LGAD.

- W7: C2-V3-2TR-GRT2
- W11: C1-V2-2TR
- W16: C1-V4-2TR and C2-V2-2TR

Submitted to the NIM A (PSD13 conference)

Methodology

- The “strong” IP signal in 2TR LGAD appears in an irregular manner. To study the ratio of “normal” to “strong” waveforms and their potential time evolution, we performed a long acquisition of 10000 individual waveforms generated in IP by single laser pulses.
- For example, in the studied experimental conditions (100V, 0.2 pJ at room temperature), about 15% of laser shots generate a “strong” signal.
- Surprisingly, we also observed several waveforms of a new type in the obtained dataset, not fitting into the “normal” or “strong” category. These new waveforms exhibited amplitude and width similar to the “strong” signal, but they occurred randomly in time, not being synchronized with the laser. This observation persuaded us to perform a test without a laser and a laser-synchronized trigger.
- Unexpectedly, this random signal, labelled as a “ghost”, existed even without laser stimulation.

- It is worth adding that recording even relatively rare events in auto-trigger mode is possible due to the extraordinary visualisation features of the used oscilloscope (Keysight 100 InfiniiVision DSOX6004A) that offers 450,000 waveforms-per-second update rate. On the other hand, “ghost” signal self-triggering with a trigger counter function let us measure their occurrence rate.

- Our results show that increasing bias decreases the “ghost” signal frequency. In addition, a temperature influence is clearly visible because, at low temperature (-20 °C), the occurrence rate of “ghost” events is significantly reduced compared to room temperature.

Sample from W11

W11: C1-V2-2TR

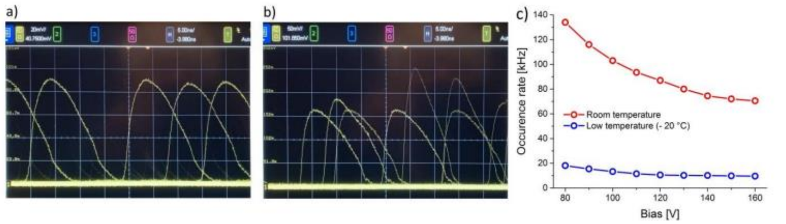
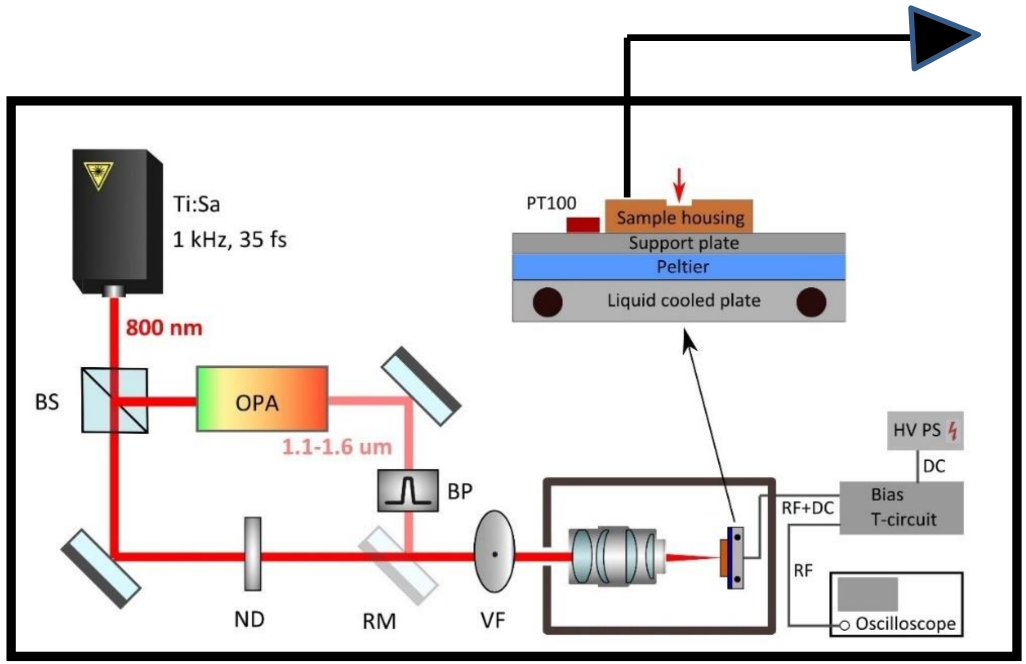


Figure 3: Examples of randomly generated “ghost signal” waveforms (oscilloscope screenshot) in 2TR TI-LGAD at a) 100 V and b) 160 V ; c) occurrence rate of the “ghost signal” vs. bias voltage at room temperature and -20 ^{0}C.

Ghosts

Experimental Technique: TCT at ELI

Place	ELI Beamlines
Operational modes	Single and two photon absorption (SPA and TPA)
Pulse energy on sample	Variable by ND filters (accuracy: 0.2 pJ)
Wavelength	800 nm (SPA), 1550 nm (TPA)
Pulse width in sensor	1550 nm, ~ 150 fs 800 nm, ~ 50 fs
Focus waist radius	0.85 µm (SPA), 1.5 µm (TPA)
Rayleigh length	3.31 µm (SPA), 7.74 µm (TPA)
Sample cooling	Down to -25 deg. C
Sample movement	X, Y, Z
Bias voltage	up to or > 720 V
Detection	6 GHz (20 GSa) oscilloscope and leakage current measurement (accuracy: 0.1 µA)

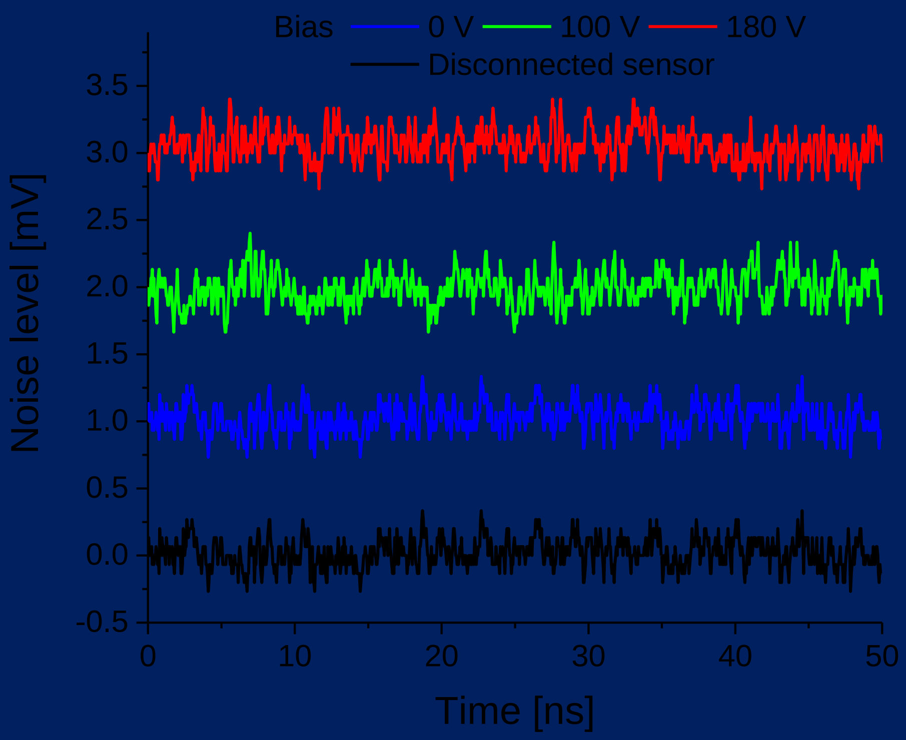


Schematic view of the setup for TCT-SPA and TCT-TPA measurements at ELI Beamlines (BS – beam splitter, OPA - optical parametric amplifier, BP - bandpass filter, ND - neutral density filter, RM - removable mirror, VF - variable filter)

In study presented here we did not use amplifier.

Ref: G. Lastovicka-Medin et al, Femtosecond laser studies of the Single Event Effects in Low Gain Avalanche Detectors and PINs atELI Beamlines, Nuclear Inst. and Methods in Physics Research, NIM A, 2022

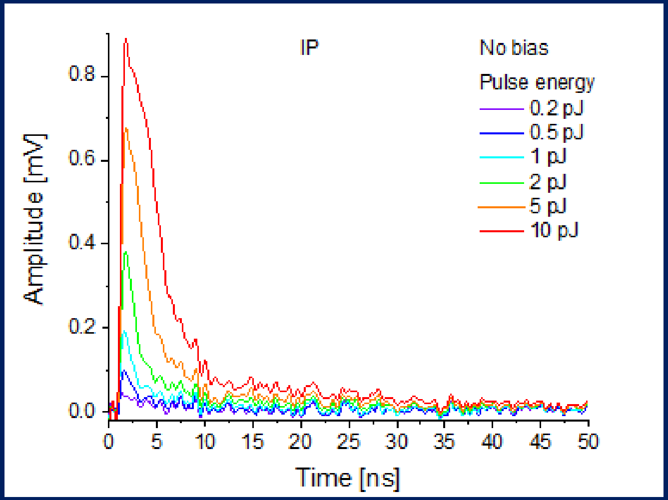
Oscilloscope noise

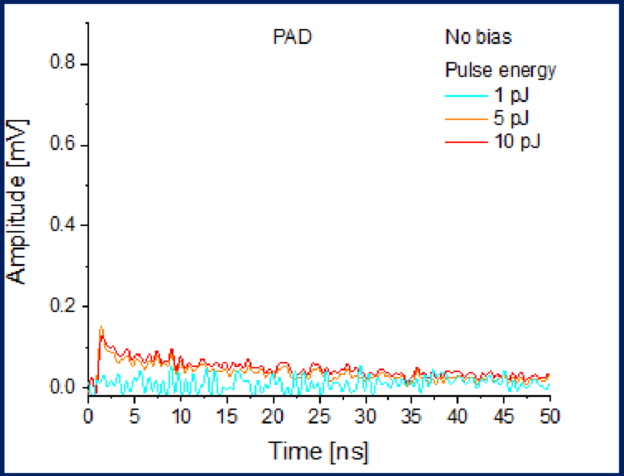


We didn't observe any meaningful difference between noise level recorded on the oscilloscope at different bias and even with disconnected sensor. In every case the noise variation is about +/- 0.25 mV

Waveforms are artificially shifted for better comparison

No bias test, only laser



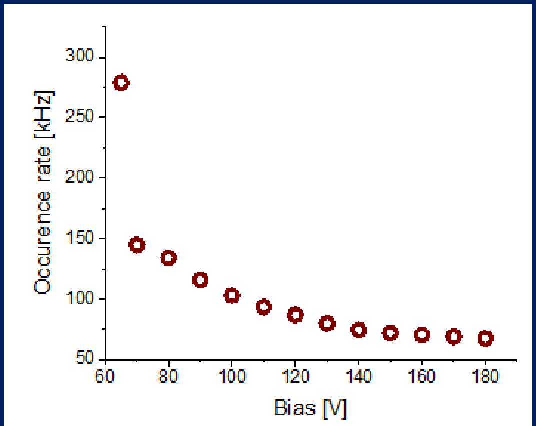


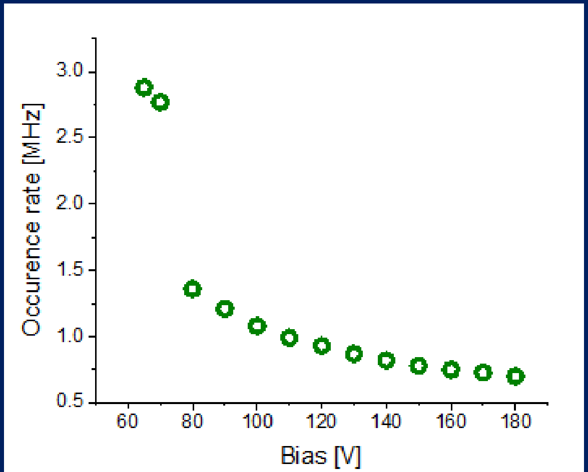
- When the sensor is not biased it's possible to see some small (but measurable) signal when IP is illuminated by laser. However this signal it doesn't look like "ghost". It reminds more on normal signal that increases proportionally to laser power.

- Interestingly, in pad region this signal is much smaller than in IP.

- Since this signal is very low (on the noise level) these waveforms were averaged over 256 laser shots and additionally smoothed

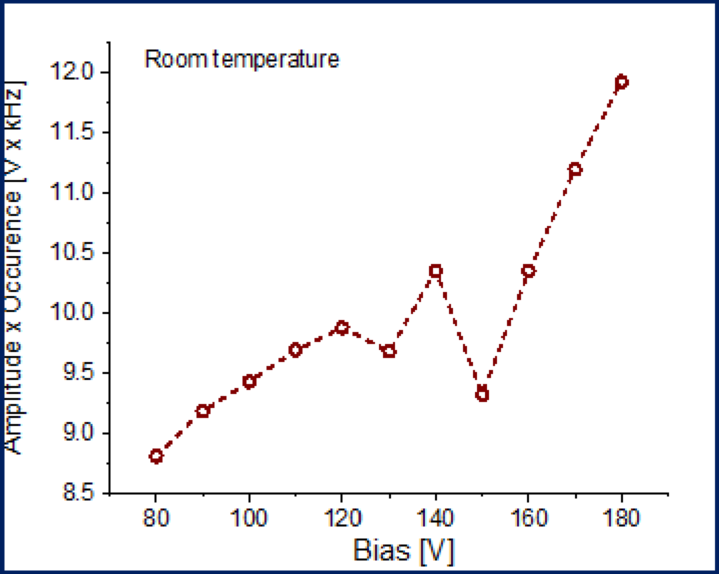
Ghost behavior under continuous illumination by lamp

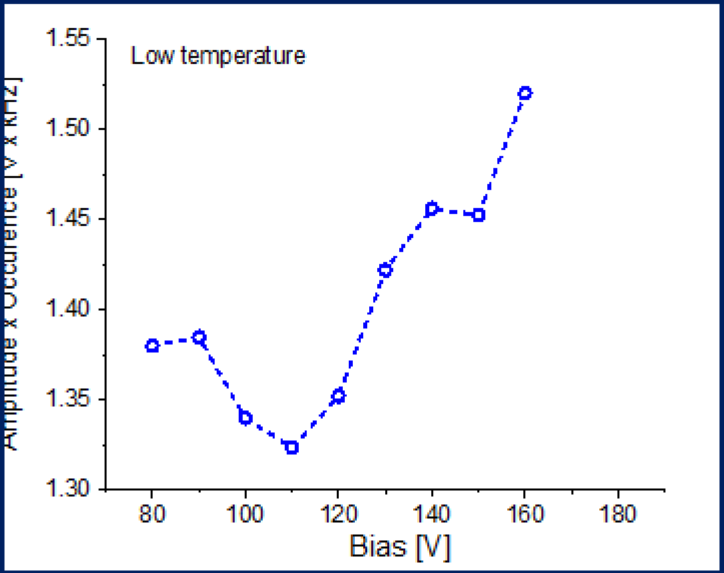




We checked how the results are affected when sensor is illuminated by lamp (continuous white light). Only change under illumination is occurrence rate of ghosts. Under illumination it increases about 10 times to MHz level. The amplitude and shape are the same. Normal was not affected by lamp illumination.

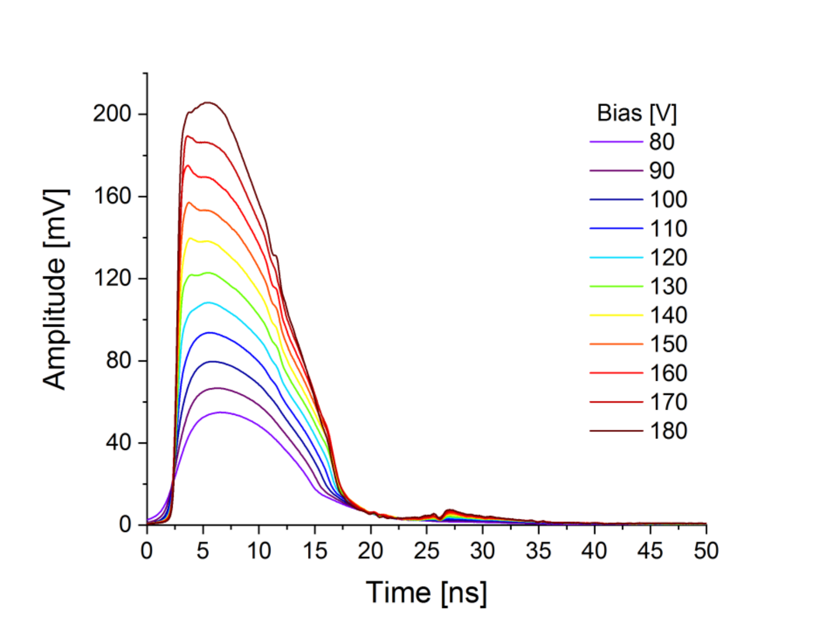
Amplitude of ghosts multiplied by their occurrence rate

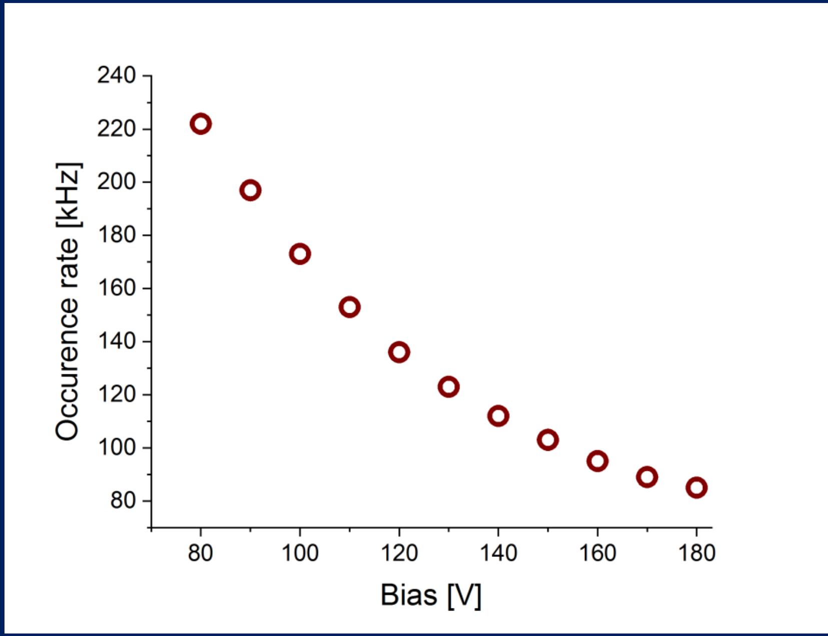




Example of ghost waveforms

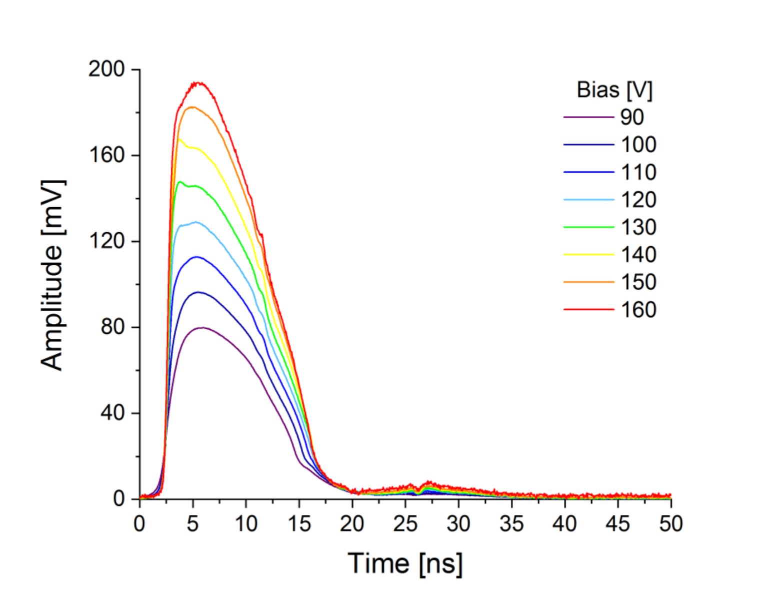
W7: C2-V3-2TR-GRT2; Room Temperature

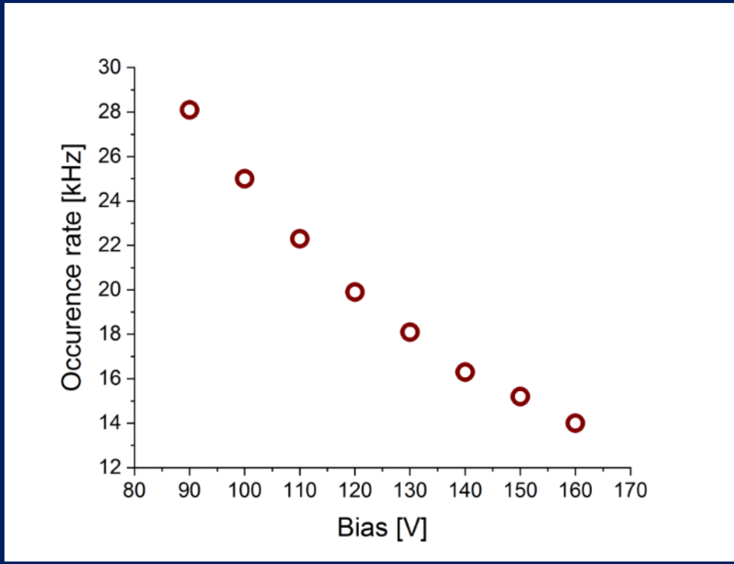




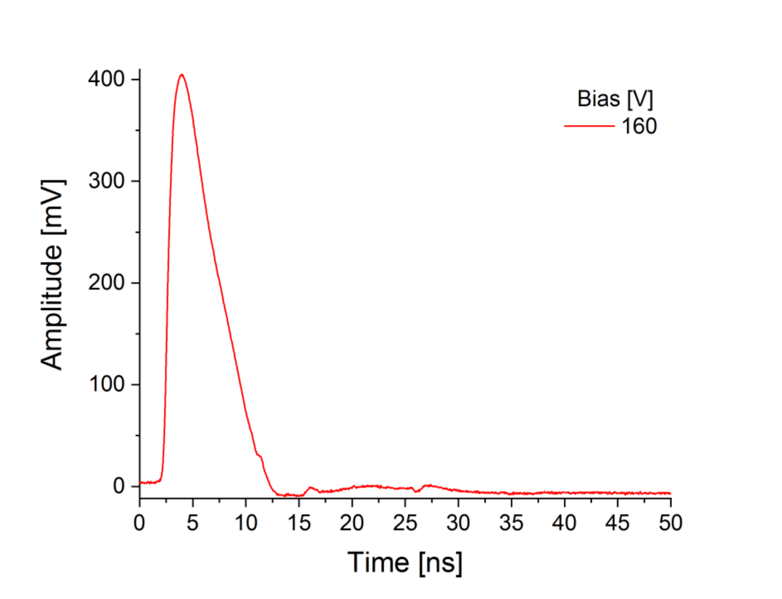
- one type of ghost waveforms is observed (threshold 75 V)
- amplitude clearly increases with bias in entire range
- width is about 11 ns and slightly decreases with bias from 100 to 180 V (see normalized plots)
- rising of signal becomes faster with bias (see normalized plots)
- occurrence rate decreases with bias

W7: C2-V3-2TR-GRT2 ,T=-18^{0}C;

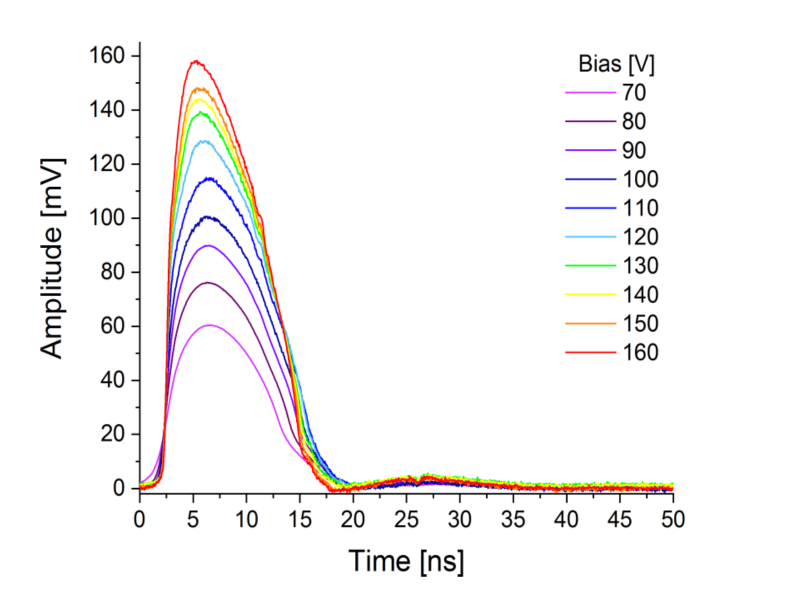


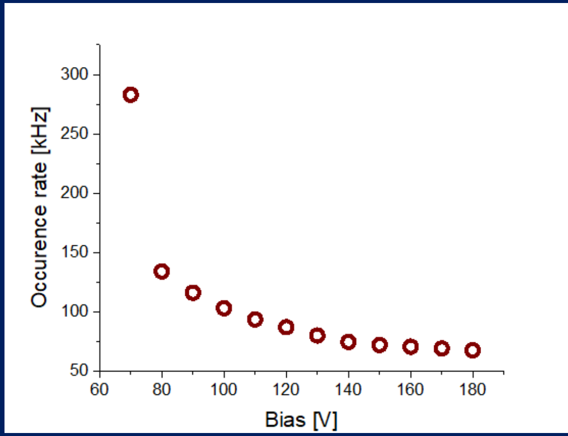


- Two types of ghost waveforms are observed
- Waveforms A are very similar to those observed at room temperature (threshold 87 V)
- amplitude clearly increases with bias in entire range
- width is about 10 ns and slightly decreases with bias from 100 to 180 V (see normalized plots)
- rising of signal becomes faster with bias (see normalized plots)
- occurrence rate decreases with bias and is about 10 times lower than at room temperature
- Additional type of waveform (B) appears at 160 V (waveforms A are still observed at this bias)
- Waveforms B are much stronger (double amplitude) and narrower (width about 5 ns) than waveforms A
- Occurrence of waveforms B is not stable and varies between 1 and 3 kHz

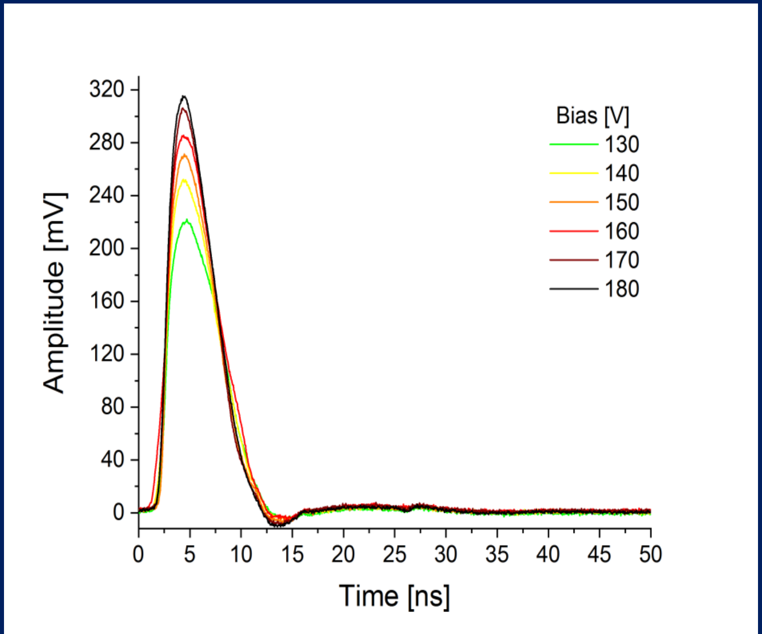


W11: C2-V2-2TR T=20^{0}C;

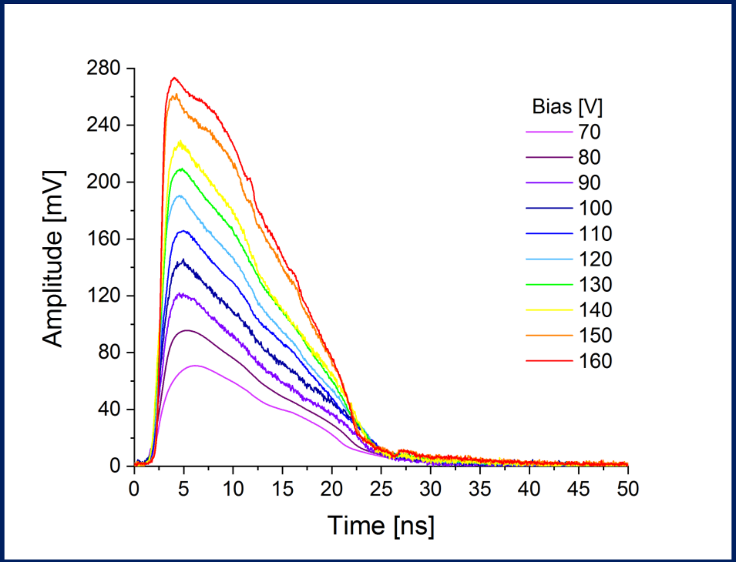


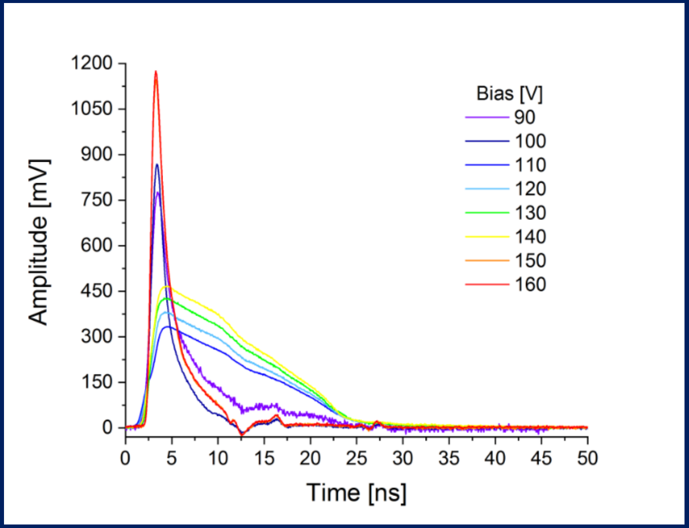


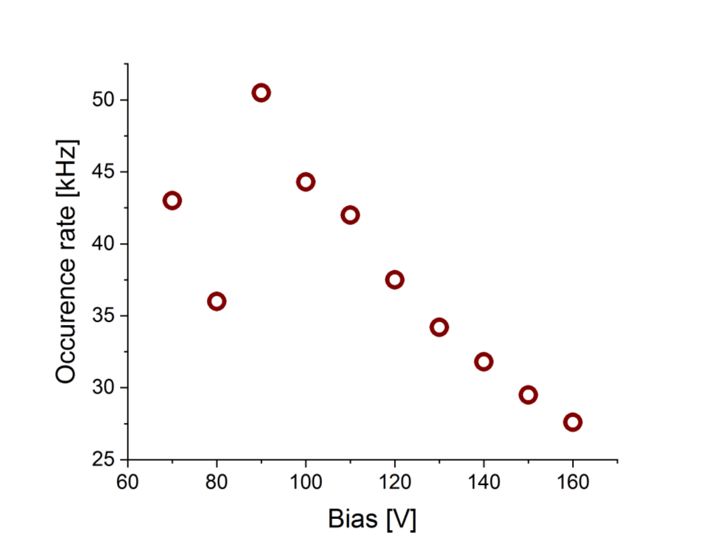
- Two types of ghost waveforms are observed
- Waveforms A appears at threshold 67 V and waveforms B at 130 V
- Amplitude of both types increases with bias in entire range
- Width of waveforms A is about 11 ns and slightly decreases with bias from 100 to 180 V (see normalized plots)
- Waveforms B are stronger and narrower (width about 5 ns)
- Rising of waveforms A becomes faster with bias (see normalized plots)
- occurrence rate of waveforms A decreases with bias occurrence of waveforms B is not stable and varies between 1 and 3 kH



W16: C1-V4-2TR and C2-V2-2TR; T=20^{0}C

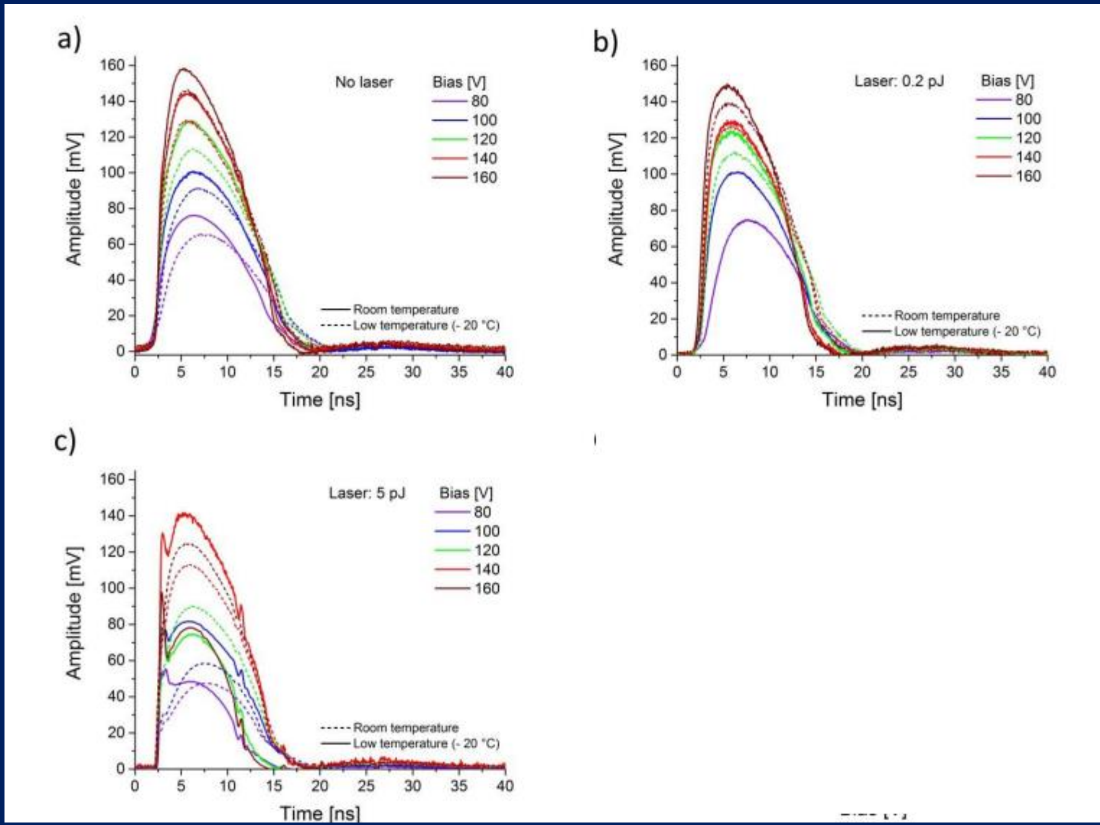






- Three types of waveforms appears for this sensor
- Waveforms A appear at 68 V and amplitude increases with bias
- Waveforms A have width about 12-13 ns which seems to slightly increase with bias
- Waveforms B appear in range 90-100 V and 150-160 V
- Waveforms B are much stronger and narrower (~2 ns) than waveforms A
- Waveforms C appear in range 110-140 V
- Waveforms C are much stronger (double amplitude) than waveforms A but they have the same width
- rising of all signals becomes faster with bias
- occurrence rate of waveforms A decreases with bias above 90 V but is irregular below this bias
- occurrence of waveforms B and C is not stable and varies between 1 and 3 kHz.

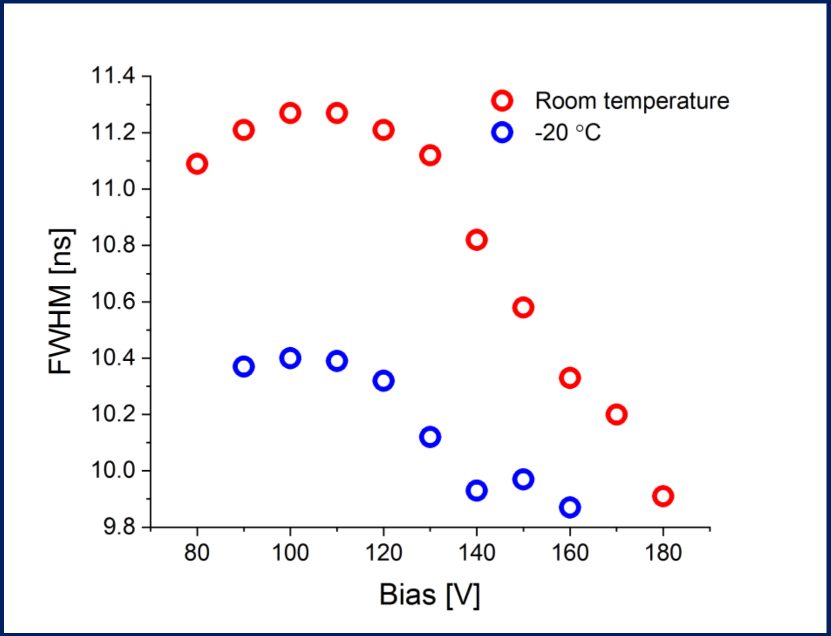
Ghost waveform compared to the laser induced signal waveform



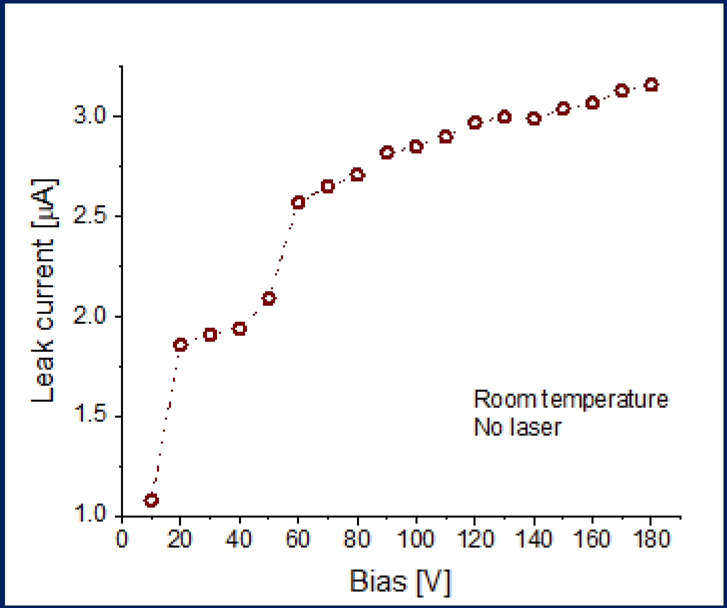
TCT waveforms measured at room temperature and -20 0 C for double trench isolated LGAD at different bias voltage:

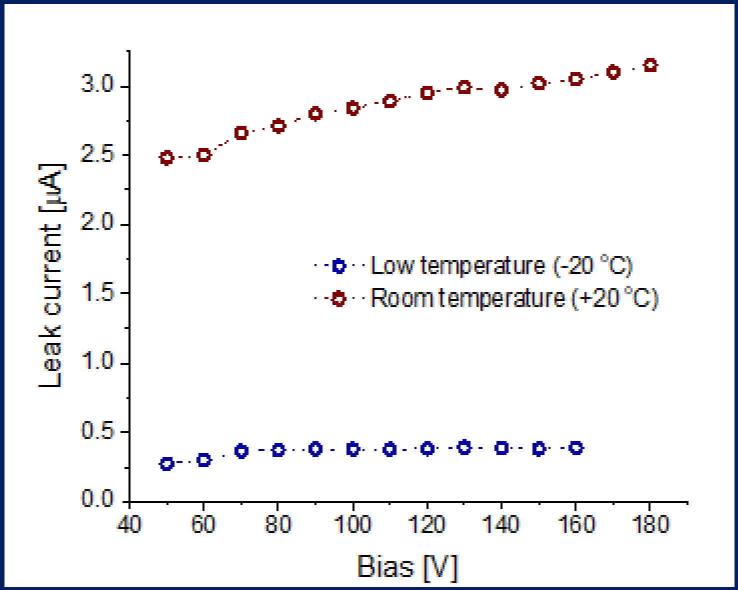
a) “ghost” signal (no laser used);
b) “strong” IP signal generated at 0.2 pJ;
c) “strong” IP signal generated at 5 pJ..

Width vs bias extracted from ghost waveforms



Leakage Current





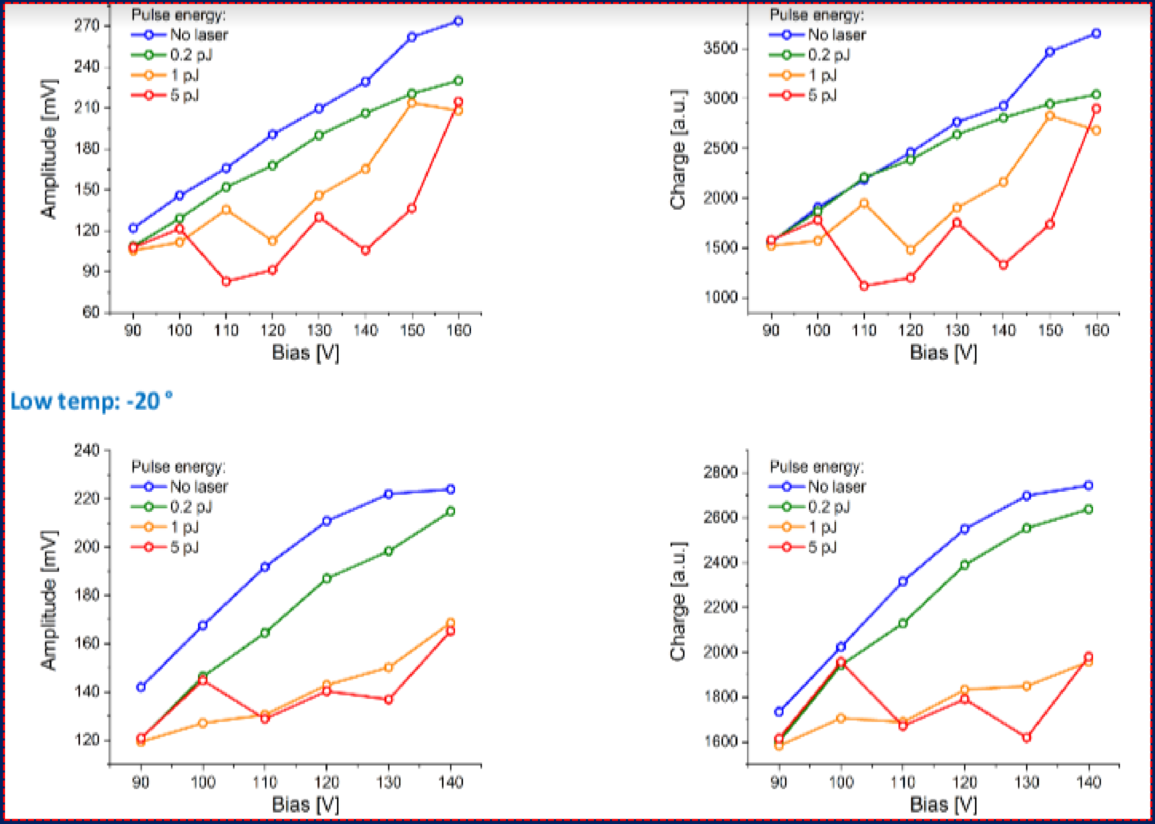
The fact that we don’t see any laser power dependence in leak current can be related to the way how it’s measured. We don’t know what is the sampling of leak current measured by our HV power supply but we guess it’s quite small. It’s probably average value measured over 1 second or so.

The signal generated by laser is very short (nanoseconds) so probably some instantaneous increase in leak current (if exist) cannot be registered by our setup.

Space charge as "quencher" for ghosts

W16: C1-V4-2TR

- ➢ By increasing the bias voltage, the amplitude of the transient current signal increased in all cases, nevertheless whether LGAD was illuminated by fs-laser or laser was not used.
- ➢ Also, in all studied cases, when charge was externally induced (by laesr), the signal amplitude decreased with increasing the laser power, and this decrease was more pronounced at low than at high bias voltages.



➢ Noticeably, in all studied cases, the measured IP signal was lower when laser was switched on than

Summery

- Unusually enhanced current when IP region of Double Trenched Ti –LGAD was illuminated with fs-laser is now explained by presence of ghosts. “Strong” IP signal seems to be superimposed in ghost signal.: when ghost signals vanished in irradiated sample, we saw that also the strong signal vanished. Pad signal is not affected by ghosts.

- Ghosts has 3-5 times higher amplitude than pad signals and 5 x larger duration.

- Amplitude of ghosts is increasing with bias; width of ghost waveforms firstly increases and then decreases with bias; occurrences of ghosts is bias threshold dependent; occurrences rate decreases with bias.

- Deeper trench has more types of ghosts then shallower trenched LGAD.

Hypotheses/Explanation

What is seen has no solid explanation yet.

We don't know yet where the "discharge" which has the shape of the "particle like" event happened, so it is impossible to claim they come from a certain region.

Based on the measurements, we would say it could have nothing to do with multiplication.

The impact ionization which is the mechanism for multiplication and eventually discharge/breakdown in silicon has exponential dependence on electric field. Therefore, it is difficult to understand how the rate of micro-discharges would go down with bias voltage, as we found in our measurements

An exercise with calculation of current, size of IP and frequency of the ghosts would help us to calculate amount of charge accumulated; however to compare it to charge seen in pulses is not straightforward due to so many uknown parametes (such as rate of generation-recombination, space charge effect that supressing the further incrtease of charge density etc).

The free holes generated either by particle or thermal current might happen. However, how can holes migrate to pixel and multiply in gain layer it is not clear, since in this case the potential is repeling and hole multiplication would mean complete breakdown of the device except if this is prevented by increased space charge

What is clear is that these ghost events in 2tR LGAD are different from what is regularly seen in other LGADs.

We can speculate that the reason can be some local accumulation of the charge which is building up (this is more likely to happen in the IP region) and then after certain potential is reached it discharges. However, it is not understood how this is done.

We can further speculate that, as at high bias the voltages potential barrier can be higher the rates would also go down, then the average signal for these discharges should dependent on bias (this is seen in measured data).

Help from FBK would be appreciated. We ned to know more precisely the cross section of IP region.